

POLAR
PAM
2037

POLARPAM

Remote sensing applications in
ice reconnaissance

by

H.G. Hengeveld

Presented at the 7th annual
Congress of Canadian Meteorological
Society. p. 1-7⁺³ charts

POLARPAM

POLAR
PAM
2037

CIR-2673
TEC-218
28 JUN 55

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

"FORMATION, PROPERTIES AND FORECAST OF ARCTIC SEA ICE"

by M.G. Hagglund

1. INTRODUCTION

The brief resume of Ice Forecasting which follows is designed to acquaint Canadian meteorologists with the present status of a science whose development in Canada should be a natural consequence of the geographic location of a large part of our vast country. Up to now the extent of Canadian participation has been limited - insofar as active support of shipping is concerned - to ice reconnaissance flights over the Gulf of St. Lawrence and the provision of Resolute based R.C.A.F. Lancasters to carry U.S. observers on ice reconnaissance missions. In the future, however, with activities in our Arctic regions continually increasing, it is certain that Canada will play a far greater and more active role in the Sea Ice programme.

The material presented herein is available in much greater detail in published U.S.N. Hydrographic Office Technical Reports and papers which the reader interested in Sea Ice should obtain.

2. HISTORICAL

Dr. Armstrong's analysis¹ of Russia's Northern Sea Route has illustrated very well how important ice reconnaissance and ice forecasting can be to a nation's economy. The geographic distribution of land and sea in the Eurasian Arctic is such that in order to develop her vast Arctic regions, the U.S.S.R. found it necessary, and also possible, to make extensive use of sea transportation in Arctic waters. Thus the U.S.S.R. has had a substantial ice reconnaissance and ice forecasting programme in operation for more than two decades. In the North American Arctic, on the other hand, a parallel programme was not begun until a scant three years ago, when the requirement for it first arose. It was not until after the summer of 1951, when U.S. sea transportation suffered losses of millions of dollars due to ice damage during Operation

LIBRARY
BOREAL INSTITUTE

DEC 20 1960

POLAR
PAM
2036

POLAR
PAM
2036

CIR-2673
TEC-218
28 JUN 55

Blue Jay, that a systematic programme of Sea Ice Reconnaissance and Forecasting was undertaken by the U.S.N. Hydrographic Office. In subsequent years, forecasting techniques have been developed as knowledge of sea ice behaviour and distribution increased. At present, the Hydrographic Office feel that it has many technological "soft spots" to repair if sea ice forecasting is to become truly a science. Their programme is one of continuous testing, by practical application, of theories advanced by their own meteorological oceanographers as well as Russian and other European scientists, so as to hasten the day when all phases of ice forecasting will have a firm scientific basis.

As a brief comparison of U.S. and U.S.S.R. Sea Ice programmes, the 1953 U.S. reconnaissance programme was approximately equal to that of the U.S.S.R. of 1941, using Observer Hours as a yardstick. In 1954 the U.S. programme was slightly greater than the U.S.S.R. programme of 1942 as well as that of 1944. Since the latter year, little information has been forthcoming on the actual extent of the U.S.S.R. programme, but we may assume that it has continued to develop, and that their ice forecasting techniques have kept in step with their reconnaissance. Present news reports of Russian Arctic activities lend added credence to this assumption.

3.

TECHNIQUES

There are three distinct phases to ice forecasting for which techniques have been or must be developed. They are Sea Ice Movement, Sea Ice Formation and Growth, and the Breakup and Disintegration of Sea Ice.

3.1

Sea Ice Movement

Nansen was the first to advance the present theory of ice drift, from his observations during the drift of the Fram in 1893-96. He found that the ice drifted an average of 28° to the right of the wind. According to the Russian scientist Zubov, the drift of an individual floe depends on three factors, namely (1) the pressure force of the wind on the ice (2) Hydrodynamic Resistance and (3) Coriolis Force. Neglecting the effects of permanent ocean currents and assuming the floe has reached a steady state condition, the relationship of these forces can be expressed by the equation $\tan a = F/R$, where

a = angle of deviation from wind direction

F = Coriolis Force

R = Hydrodynamic Resistance

Figure 1 shows the resolution of these forces and the resultant motion under steady state conditions.

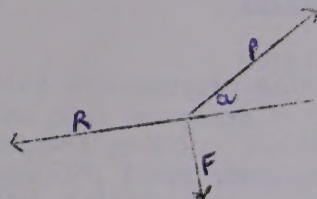


Fig. 1

P = Pressure force of wind

F = Coriolis force

R = Hydrodynamic Resistance

$\tan a = F/R$

Nansen has also calculated the speed of ice drift, assuming the pressure force of the wind is proportional to the square of the wind speed and that the resistance to motion is proportional to the drift speed. The speed will also depend on the degree of hummocking and on the concentration of ice. The greater the hummockness, the higher will be the wind coefficient; and the greater the concentration, the lower the coefficient. Table I shows the wind coefficient, or ratio of ice drift speed to wind speed, expressed as percentage, for various concentrations and hummockness. The Hydrographic Office forecasters most frequently use that portion of the table corresponding to hummockness 5 and concentrations from 1 to 9.

m	Cn 1	2	3	4	5	6	7	8	9
1	0.9	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.3
2	1.8	1.6	1.4	1.2	1.1	0.9	0.7	0.6	0.5
3	2.7	2.5	2.2	2.0	1.8	1.5	1.3	1.0	0.8
4	3.6	3.3	3.0	2.6	2.3	2.0	1.6	1.3	1.0
5	4.5	4.1	3.7	3.3	2.9	2.5	2.1	1.7	1.3
6	5.4	4.9	4.4	4.0	3.5	3.1	2.6	2.1	1.6
7	6.3	5.8	5.2	4.7	4.1	3.6	3.0	2.5	1.9
8	7.2	6.5	6.0	5.4	4.8	4.1	3.5	2.9	2.2
9	8.1	7.4	6.7	5.9	5.2	4.5	3.9	3.1	2.5

TABLE 1 ICE DRIFT TABLE

SPEED OF ICE DRIFT (Percent of Observed wind) for varying concentration (Cn) and hummockness (m)

In actual practice, the observed ice is advected along the isobars, since the deviation of surface wind to the left of the isobars is approximately equal to the deviation of ice drift to the right of the wind direction. The effect of the permanent currents is also taken into account. Transparent overlays are used to facilitate the vectorial addition of wind drift and current drift to obtain a prognostic chart of ice conditions.

3.2

Formation and Growth of Sea Ice

Considerable effort has been devoted by the Applied Oceanography Section of the U.S.N. Hydrographic Office in the past two years to the theory of ice formation and its subsequent growth. The theory is based on the concept of "Ice Potential", first advanced by Zubov in 1938, for forecasting initial formation of ice, and its application subsequently, along with "degree days of frost" to forecast ice thickness, taking into account as well, other physical factors affecting ice growth.

The amount of ice which will form in a given area during an ice season depends not only on meteorological conditions, but on the amount of thermal energy stored in the water mass and upon the rate at which convective mixing takes place. A model of convective mixing is selected which will explain the variation in thermohaline conditions caused by heat removal and ice accretion. Before a forecast can be made, it is, of course, necessary to obtain oceanographic measurements within the area in question to obtain information on temperature and salinity and hence the thermal energy stored in the water mass. These measurements are best made after the reversal of the heat budget, otherwise the amount of heat added prior to the reversal must be computed before the ice potential method can be applied. Establishing the ice potential of a column of water requires knowledge of temperature and salinity at N levels within the column. The column is then divided into $N-1$ layers and the mean temperature, mean salinity and mean density are computed for each layer. Considering only the first layer, after mean temperature, salinity and density are computed, the column is said to be "partially" mixed down to the second level, i.e., there is no heat loss involved. "Complete" mixing is achieved by cooling the partially mixed column until its density equals that of the original second level. A potential heat loss is required to

bring this about. The complete mixing can be accomplished by merely lowering the temperature of the partially mixed column, provided the water is not cooled below the freezing point. If a temperature change is necessary such that the freezing temperature is reached, then ice will form and a known percentage of salts will be frozen out of the ice to increase the salinity of the remaining water in the column. By carrying out mixing, layer by layer in this manner, it is obviously possible to determine the potential heat loss necessary for initial ice formation. The time required and therefore, the forecast of initial ice formation is then obtained by consideration of climatological data and the sun's altitude in addition to the oceanographic data.

Following initial ice formation, the processes by which heat is removed from the water column are considerably altered. Any heat which is then removed from the water must be conducted through the solid layer of ice, and possibly snow, above it. Hence the rate of further heat loss is determined by the temperature gradient through the ice and snow. The number of degree days of frost during the ice growth season can, therefore, be applied to obtain a forecast of future ice thickness. (A degree day of frost is defined as a day with a mean temperature 1 degree below the freezing point of sea water).

The above is a bare outline of the qualitative approach to the problem. For the full treatment the interested reader is referred to the technical report on the subject by Simpson and Lee². Their report details a technique whereby (1) the ice potential for each oceanographic station is calculated; (2) from available meteorological and oceanographic data, the date of ice formation is calculated (3) the forecast of ice growth is made in terms of degree days of frost.

Almost simultaneous with the Simpson and Lee report, Brown³ devised a graphical method, by which the ice potential of a water column can be quickly determined without recourse to the more laborious layer by layer mixing method of Simpson and Lee. It also shows very quickly whether ice formation is probable, enabling the long range forecaster to limit the detailed analysis of oceanographic data to those areas where ice formation is indicated.

3.3

Disintegration of Sea Ice

In his paper on Ice Forecasting, presented before the American Meteorological Society meeting in January, 1955, W.I. Wittman⁴ states "The increased objectivity attained in 1954 in the forecasting of sea ice formation, growth and movement was not matched in the forecasting of sea ice disintegration. However, a much better understanding was obtained of this complex process and individual skill in forecasting subjectively was achieved". This aptly sums up the present status of this phase of ice forecasting.

Sea ice disintegration is primarily due, of course, to rising air temperatures and increased solar radiation. Brine cells trapped in sea ice expand as temperatures rise, and then gravitate downwards through the ice more readily, increasing the porosity of the ice, the process becoming most rapid and noticeable when air temperatures rise above the freezing point. The final result is "rotten" porous ice which breaks up readily. In many areas, to be sure this stage is never reached, and the ice lingers from year to year, becoming fresher each year and, therefore, less likely to the disintegration process. In addition to this basic cause for ice breakup, the action of wind, waves, warm air advection and warm precipitation must be considered, especially along a pack boundary where storm action effects are most pronounced. In coastal areas, river runoff, the occurrence of Foehn winds in certain areas, tidal action, and the increased absorption of solar radiation due to soiling and to bare coastlines, hasten the breakup process and the formation of shore leads. This phase is therefore one in which the experienced ice forecaster will have more success than the neophyte, and wherein climatological statistics, ice climatology, synoptic ice conditions and long range meteorological forecasts of temperature and expected storminess must each be given due consideration if any degree of success is to be achieved.

4.

OPERATIONAL ICE FORECASTS

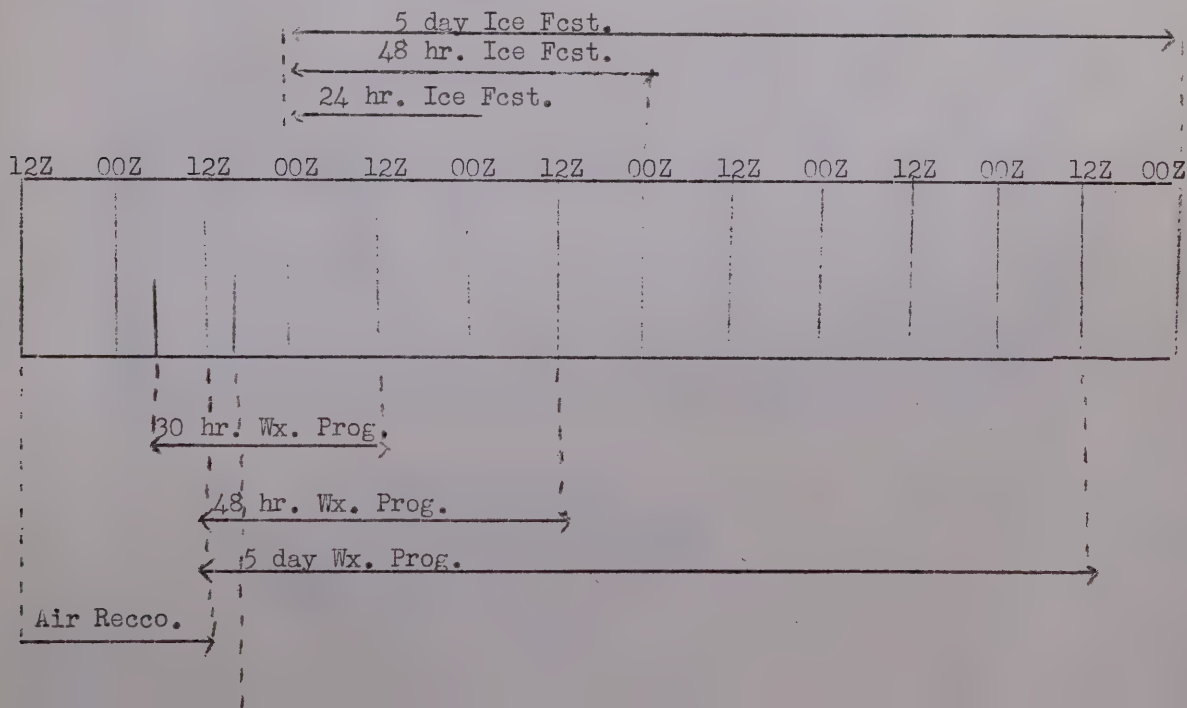
In addition to the intensive development programme mentioned above and which also includes the collection and processing of ice data, "Ice Climatology", and the translation and study of U.S.S.R. literature on ice forecasting, the U.S.N. Hydrographic Office is very active on the operational side, the preparation and issuing of ice forecasts. Forecasts fall into four categories; namely short-range, of 24 or 48 hour duration; long range, or 5 day; extended or 30 day; and outlooks, of 150 days duration. Short range

CIR-2673
TEC-218
28 JUN 55

are issued either by the Central Office or at Arctic field stations, such as Goose Bay, Resolute, Thule or Kodiak. The remainder are all issued from Washington. Last year 548 forecasts were issued and of this total, 228 originated in the field.

A detailed discussion of the preparation of an ice forecast will not be attempted in this resume. However, meteorologists from their familiarity with the preparation of weather forecasts, can readily visualize the steps necessary in the preparation of, for instance, a short range forecast. Figure 2 shows graphically the time relationship which exists between Air Reconnaissance, prognostic weather charts and Ice Forecasts of up to five day's duration. Due to the time elapsing between the air reconnaissance and the beginning of the valid period of the ice forecast, it is invariably (except in the field office) necessary to "hindcast" to bring observed ice conditions up to date, using meteorological data received after the air reconnaissance was completed.

For extended, or 30 day ice forecasts, the extended weather forecasts issued by the U.S. Weather Bureau are probably the most important tool, and for outlooks, a preliminary ice reconnaissance, climatological data, ice climatology, and again the U.S. Weather Bureau 30 day forecast for the first part of the period, are made use of to arrive at an extremely generalized forecast of future ice conditions.



REFERENCES

1. Armstrong, T., 1952, The Northern Sea Route. Cambridge University Press, Cambridge, England.
2. Lee, O.S. and Simpson, L.S., 1954, A Practical Method of Predicting Sea Ice Formation and Growth, TR-4, U.S. Navy Hydrographic Office, Washington, D.C.
3. Brown, A.L., 1954, An Analytical Method of Ice Potential Calculation. TR-5, U.S. Navy Hydrographic Office, Washington, D.C.
4. Wittman, W.I., 1955, Resume of U.S. Navy Hydrographic Office's Ice Reconnaissance and Forecasting Programme for 1954.
5. Bates, C.C., Kaminski, H., and Mooney, A.R., 1954, Development of the U.S. Navy's Ice Forecasting Service, 1947-1953 and its Geological Implications. Trans. N.Y. Acad. Sciencies, Series 2, Vol. 16, pp. 162-174.

APPROVED

J. Archibald
for Andrew Thomson,
Controller.

2036

STN

'84

FEB 5 79

"Fermata"

8.1

ALP

50

tic

Date Rec

REMOTE SENSING APPLICATIONS

in

ICE RECONNAISSANCE

June 1, 1973

H. G. Hengeveld,
Ice Division,
Central Services Directorate,
Atmospheric Environment Service.

2036

FEB 5 78

184

ALP

50

"Formation

9.4

tic

Date Rec

I INTRODUCTION

With recent advances in technologies associated with data collection techniques, whether research or operationally oriented, the term 'remote sensing' has become a very popular and "in" type of expression. We are familiar with the use of the term "remote sensing" in such fields as forestry, agriculture, geology, meteorology, and so on. It is not surprising, therefore, that remote sensing has also found its applications in ice reconnaissance. And rightly so! For a Canadian ice reconnaissance operation responsible for ice service to marine activities in Canada's ice congested waters cannot remain a fair weather, strictly visual observation program for very long and still effectively meet the increasing ice information requirements. As marine traffic on our ice covered waters continues to increase, particularly in our north, the demand for reconnaissance data collection through storm systems, where ice movements become most significant, as well as during darkness, whether of short or Arctic winter duration, is becoming forcefully apparent. And only new and advanced techniques of data collection and communications can hope to meet this demand.

II ICE DATA REQUIREMENTS

Let us first examine the type of information required in an ice services program as to what is and is not available without the aid of remote sensors. Section A of Figure I provides a breakdown of ice parameters for which required information is available by visual observing techniques. This information is available during daylight and below cloud ceilings only. Section B provides a further

MONTREAL INSTITUTE

LIBRARY

JAN 9 1974

rec'd:

Order No. Free

Price

Acc. No. Atmospheric Env. Service

FEB 5 78

78

2036

ALP 50

"Formation

8.4

tic

Date Rec

breakdown of ice information which requires remote sensing techniques to be available. Also included are several as yet untouchables, such as ice thickness, salinity and pressure measurements, the measurements of which modern remote sensing technologies have as yet not provided a break through.

Cloud cover has been apparent as a significant problem from the beginning of ice reconnaissance history. Early in the development of the Canadian ice reconnaissance program, the ground mapping radar became a vital on board sensor to provide ice edge information through as well as below cloud cover and beyond visual range. The current Electra ice reconnaissance platform utilizes a 3cm Echo radar equipped with a 60" scanning antenna (Figure II) and a 16" fibre optics radar screen (Figure III) to provide the supplementary data. The radar provides all weather information of location and sizes of open water leads and areas and general ice edge outlines. Detail of surface information is still, however, insufficient for determination of ice types or other physical ice parameters. The radar image is real time but does not provide a permanent record.

Recognizing the deficiencies still existing in a program employing visual and ground mapping radar observations only, the Ice Division has during the last four years, been active in the evaluation of recent advancements in remote sensing technologies as to their application in the ice reconnaissance program. A number of sensors have as a result been installed on the Electra aircraft and are being coordinated into the observing program. Others showing promise are undergoing further evaluation. These are the

Feb 5 79
 2036
 ALP 50
 4
 Permatex
 9.4

三

2036

ALP

41 Fermentation

26

tic

1000 1/2 1/2 1/2 1/2

100 - 100

sensors which I wish to discuss.

III APPLICATIONS OF REMOTE SENSING TECHNIQUES

In the evaluation of ice reconnaissance application of recently developed remote sensing techniques several questions are considered. Does the system provide real time interpretable data? Does it have a hard copy data output? Does it provide useful data unavailable by visual or ground mapping radar observations? Does it have an all weather and/or darkness capability? Will it provide a valuable function in an ice services program? Several sensors have proved capable of meeting all these criteria. Others do not meet all criteria but remain useful in a reconnaissance program.

1) Infrared Line Scan System

All bodies radiate energy by virtue of their temperature. Planck's radiation law indicates that the intensity of this radiation is a function of the body's temperature and emissivity. Over the entire spectrum this reduces to $E = \epsilon T^4$ (ϵ = emissivity). In the infrared region (the complex equation is used for finite intervals), therefore, ice surfaces at different temperatures but with relatively uniform emissivities, provide varying radiation emissions indicative of ice conditions. A scanning radiometer, known as an infrared line scan system, is used to record in the 8 - 14 μ region a two dimensional image of the surface thermal patterns. An image is developed through the displacement of successive radiometer scans over the surface from the preceeding scan through the motion of the platform. The image can be recorded both on 70mm film and in real time on a light sensitive chart paper by means of a fibre optics type recorder. The real time image,

FEB 5 79

STN 84

2036

ALP 50

"Formation"

9.4

tic

100-102609

Date Recd

4/....

which displays four to five levels of grey, can then be interpreted immediately and the information used in tactical marine support. Such a system has already been introduced on the Electra aircraft, and training in operation and interpretation is in effect. Control panel, real time recorder and the signal monitoring oscilloscope can be viewed on the right side of Figure IV. Although unable to penetrate through cloud the system has full darkness capability. During freezing weather information on relative ice thickness, amounts of ice ridging and rafting, presence of leads, cracks and frozen puddles, presence of ice pressure implied by recent fracturing, and formation of new ice or approach of thaw temperatures is available. In the melt season, ice surfaces lose their temperature contrast but form characteristic puddling patterns easily recognizable on IR. Ridges are identified as zones of no puddling. Drift directions are frequently apparent from thermal patterns on adjacent sea surfaces. Figures V, VI, and VII show examples of these features.

II) Laser Profilometer System

The laser systems transmits and receives the return of a 25 m watt modulated laser beam. Variations in the distance of travel of the beam are measured by recording change in the phase of the modulated beam during transit. Scale of these variation measurements can be changed from 10 to 100,000 feet in factors of ten simply by changing the modulation frequency. The resultant recorded trace is, therefore, a line profile of the surface topography with the aircraft altitude perturbations superimposed. The information is recorded in real time on a galvanometer light beam recorder onto

FEB 5 78

784

2036

ALP 50

"Formation

8.4

tic

Date Recd

light sensitive paper. On the 10' scale, accurate measurement of ridge heights, widths and frequencies, as well as surface roughness patterns can be obtained along the aircraft line of flight. Figure IV shows the installed control panel and recorder to the left of the Electra remote sensor station. Figure VIII provides an example of the laser trace. Techniques of analysis and information coordination are now being implemented.

The system has also been employed in a study of attenuation of wave heights at ice edges.

III) Aerial Camera System

Three 70mm Vinten cameras have been installed on the ice reconnaissance aircraft in a tri-metrigon type of arrangement to provide a wide swath of coverage. Each camera is equipped with automatic iris to compensate for high variations in reflection characteristics of surfaces being photographed. Controls allowing activation and adjustments of the cameras are located at the remote sensor station in the cabin. Although not providing real time, all weather, or night time data, the photography allows the development of a hard copy climatological data bank useful for marine planning purposes, as well as for "ground truthing" in other sensor data collection projects.

IV) Side Looking Airborne Radar

Other than ground mapping radar, none of the previous sensors provide an all weather data collection capability. Range of coverage is also a problem. The ground mapping radar on the other hand lacks resolution to provide sufficient detail of ice surfaces for

2036

FEB 5 78

ALP

50

"Fermat's

9.41

Comp 551-326.03

Date Due

anything but silhouette outlines of ice cover. A very promising tool for removing these deficiencies is becoming apparent in the Side Looking Airborne Radar (SLAR). Existing models have such features as hard copy, near real time, film type imagery output, variable swath of coverage from 25 km to 200 km, resolution of 30 meters and better, and total cloud penetration, severe thunderstorms excepted.

To date, several projects designed to determine ice reconnaissance applications of SLAR have already been undertaken. The last trial in April, 1972, executed in cooperation with DND and using their Motorola APS - 94D SLAR, provided excellent imagery of ice in the Gulf of St. Lawrence in scales varying from 1:250,000 to 1:2,000,000. Since then, DND has forwarded additional duplicates of imagery recorded in the Canadian Arctic this winter. The results are extremely encouraging. Not only open water areas, but various ice types, surface features, and concentrations can be identified. Interpretation is subjective and requires considerable experience for reliability, but aids of other sensor data in interpretation should be useful. Figure IX is an example of imagery in 1:500,000 scale over Northumberland Strait. A second example was taken over Chaleur Bay in 1:250,000 scale. Open water, fast ice, solid first year floes, surface features and heavily broken ice are identifiable. Although costs are high plans are to implement SLAR in the program by 1976.

IV) Conclusion

In summary, the ice program already has or proposes to have the capability of acquiring meso scale as well as limited

FEB 5 78

578 84

2036

ALP

50

"Fennixia"

9.41

ic

Page 1

7/....

microscale ice data under all weather, day and night conditions in the near future. Thermal imagery and laser data will provide information suitable for nighttime operation as well as detailed surface data. SLAR will provide the all weather capability and large aerial coverage. However, the problems of measurement of parameters such as ice thickness, salinity and pressure remain and current remote sensing technology has as yet not achieved a satisfactory solution to any of them. Microwave techniques under study in Canada show promise in ice thickness measurements. It appears unlikely, however, that such a system will be adaptable to fixed wing aircraft applications in the near future.

FEB 5 78

84

2036

ALP

50

"Permatio,"

9.41

ic

50.423-1.22-1947

Date Recd

FIGURE I

REQUIREMENTS FOR ICE DATA COLLECTION

A/ Available by Visual Methods

- ice type, age and mean floe size
- concentration
- snow cover, ridging, rafting
- location of leads, open water, ice edges
- iceberg count

Note: Range up to 30 miles during daylight and below cloud ceilings only.

B/ Unavailable by Visual Methods

- all parameters in A during darkness and/or low cloud cover
- data beyond 30 mile range
- ridge heights, widths, frequencies
- ice roughness characteristics
- ice thickness
- ice pressure
- ice salinity
- snow cover depth
- surface temperature

FEB 5 78

1978

2036

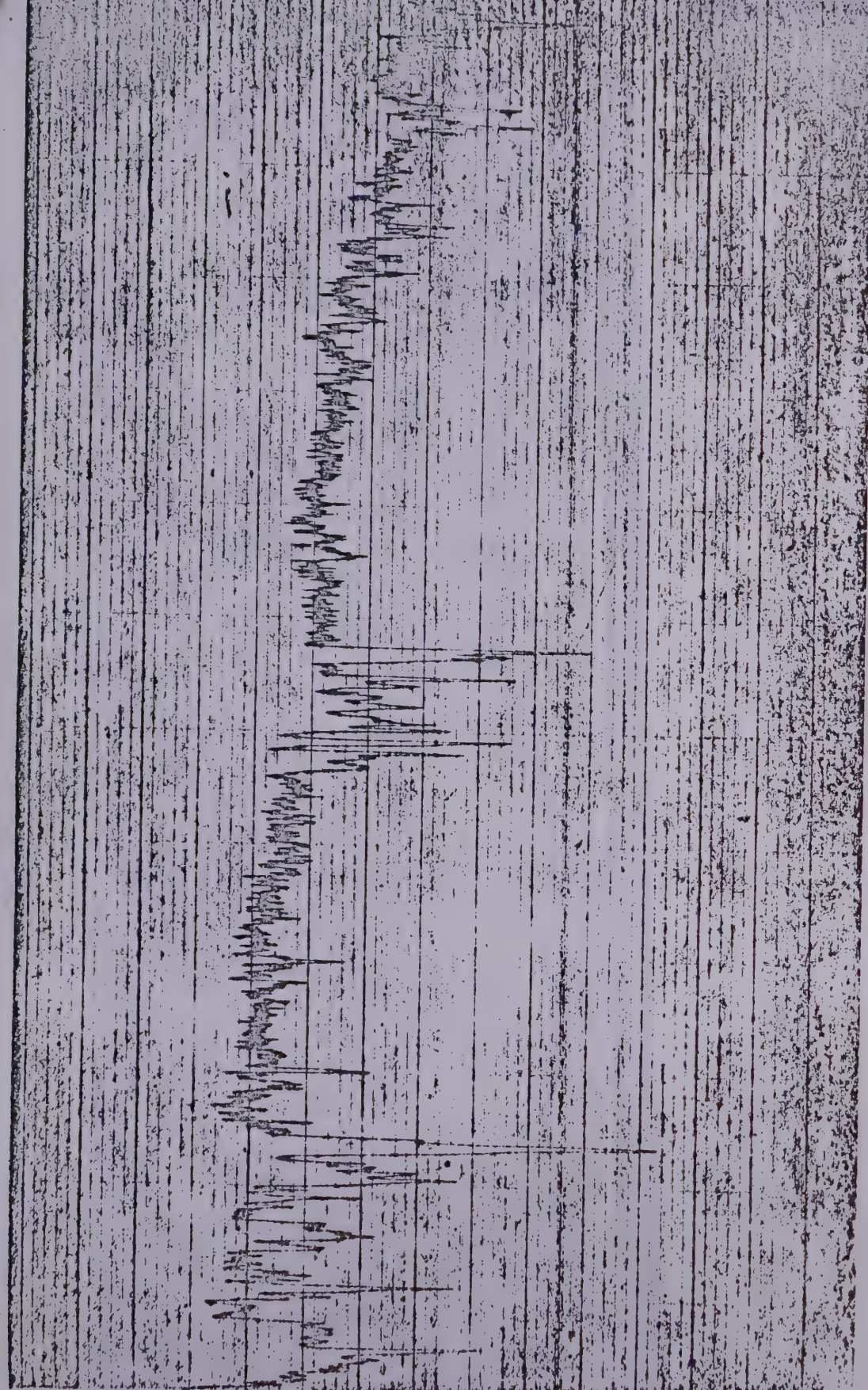
ALP 50

Formation

9.41

ic

Not Due



FEB 5 78

PM '84

2036

ALP

50

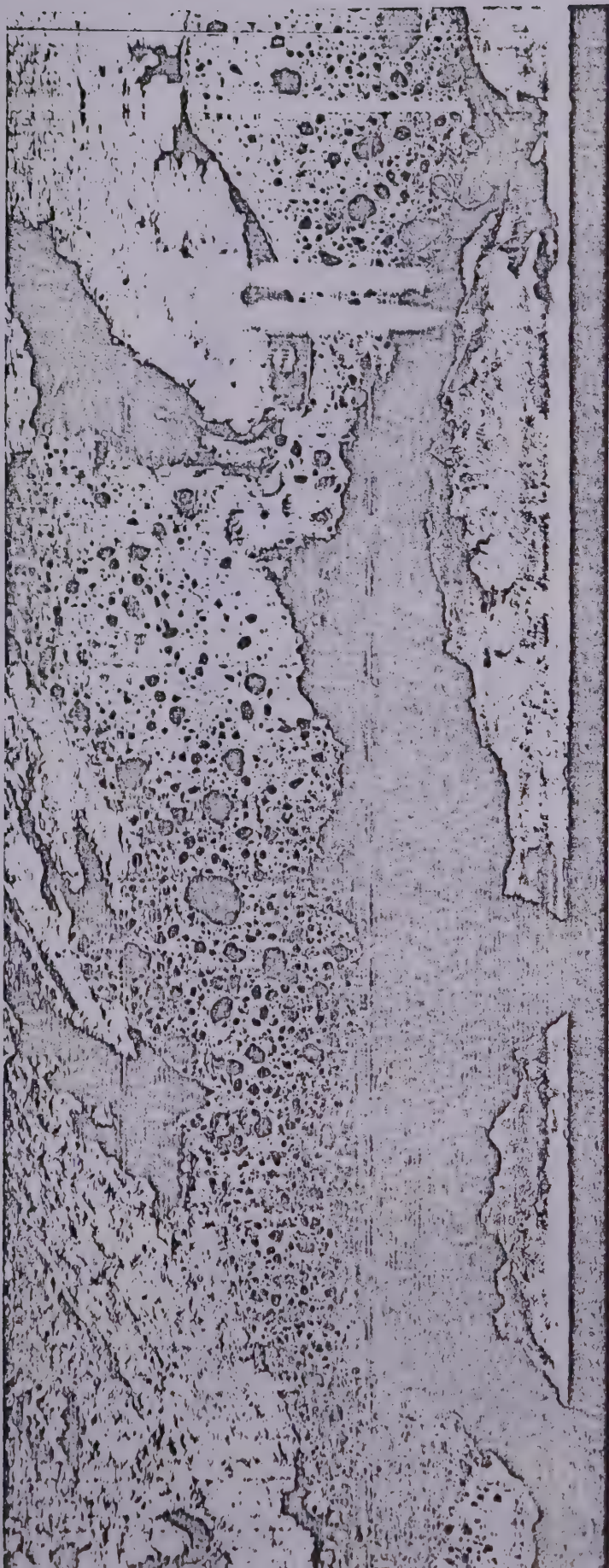
"Fennixia,"

9.45

1001-1004-05

Date Recd

WILURe IX : Northumberland Strait. 1:500,000



Electron

FEB 5 78

578 '84

2036

ALP 50

"Fermion"

9.4

ic

1978-1984

Date Recd

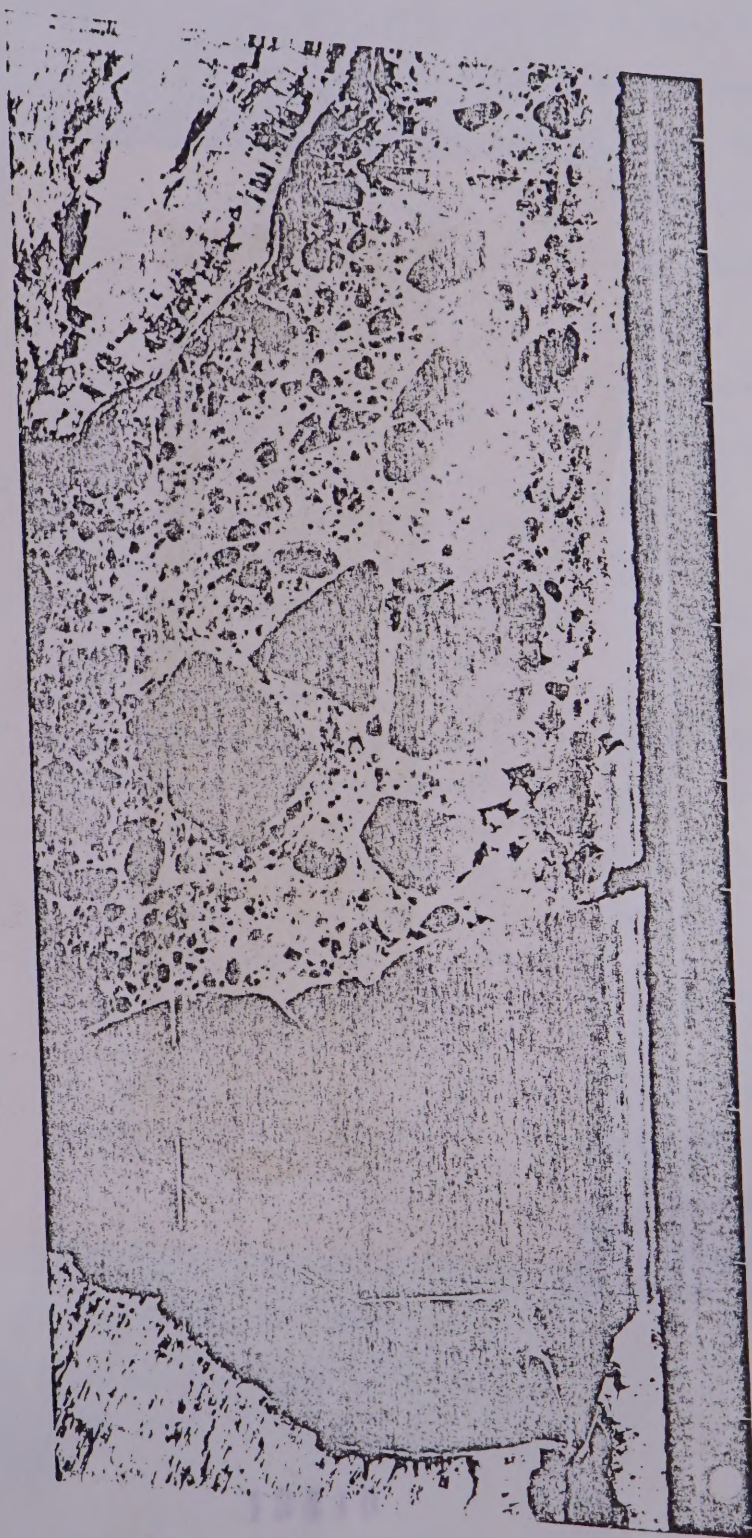


FIGURE V: Scale 1:250,000 - Chaleur Bay

Date Due

13410

Pam:551.326.032: (*41N)
HEN

HENGEVELD, H.G.
Remote sensing applications in
ice reconnaissance

DATE LOANED	BORROWER'S NAME	DATE DUE

13410

Pam:551.326.032: (*41N)
HEN

HENGEVELD, H.G.
Remote sensing applications in
ice reconnaissance

**KEY-FILE
FILING FOLDER**

M4½ LEFT

**A
KEYSTONE PRODUCT
MADE IN THE WEST**

University of Alberta Library



0 1620 0332 6129